

**METHOD AND APPARATUS TO CONTROL THE
OPERATING SPEED OF A MANUFACTURING FACILITY**

Related Applications

This is a Continuation-In-Part of U.S. Patent Application Number
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FIELD OF THE INVENTION

The present invention relates generally to the control of machinery, and more particularly controlling operating speed of equipment in a manufacturing facility.

BACKGROUND OF THE INVENTION

Current control systems of the machinery and processes of a facility in the manufacturing industry generally run equipment and processes as fast as possible, while maintaining a set level of quality. The focus of control is on the current and historical operating characteristics of the particular piece of equipment, with a particular emphasis on output quality. The controls are sometimes designed to maintain maximum operating speed and the operator manually assesses and controls operations to maintain a targeted acceptable quality. Conversely, the controls may be designed to assess the operation of the equipment to assure that it is maintaining an acceptable quality of product while the operator forces the equipment to higher levels of production. In either case, the assumptions that faster is better (if quality is acceptable), underlies the prior art control systems. This is a faulty assumption: faster might actually be less desirable.

Controls are, therefore, designed to monitor, assess and aid in improvement of the quantitative and qualitative efficiency of the particular piece of equipment. For example, in certain industries scanning devices are used on the finished end of a machine to determine if the product has achieved adequate levels of certain characteristics. If these measurements detect a trend in the finished product towards unacceptable quality, the machine speed or other items may be automatically or manually adjusted (usually downward) to assure that

1 adequate product quality is obtained. Similarly, the machine control system or operator
2 personnel will monitor the amount of down time or excessive poor quality that occur on the
3 machine. Again, speed or other items may be adjusted (usually downward) on the machine
4 to reduce the number of breaks to assure that productive efficiency is achieved.
5 Alternatively, if quality and the number of breaks are acceptable, the speed may be adjusted
6 upward.

7 Production adjustments based on down time or subsequent quality problems
8 discovered downstream are, however, predominately performed manually by operators who
9 informally estimate whether the number of breaks or the quality deterioration is severe
10 enough to merit adjustments, such as a reduction of machine speed. There are, in other
11 words, no automated control systems that currently control the operating speed in response
12 to productive efficiency of a manufacturing machine.

13 An evaluation of the production efficiency is dependent on several variables and,
14 therefore, an operator does not have all the necessary information to determine the ideal
15 target operating speed. Thus, all adjustments based on efficiency are merely estimates to
16 hopefully target ideal operating speed, even for the most experienced operators.
17 Consequently, the operator unknowingly selects an operating speed based on a few obvious
18 variables relating to inefficiencies. This selected speed may be, however, considerably far
19 from the optimal operating speed. Further, changes to the operations that effect efficiency
20 can occur rapidly, while manual reactions based on operator observations typically lag
21 considerably behind. This lack of complete information and timely reaction greatly reduces
22 the efficiency of the equipment operation.

23 While operating speed of manufacturing equipment may be adjusted directly by
24 control of the machine drive, it is often adjusted by changes to a separate piece of equipment
25 which by changing its conditions changes the speed of the machine. For instance in the
26 paper industry adjustments to the steam pressure of the paper machine dryers will effect the
27 speed. For example, when production is to be decreased, either manual input or machine
28 controls first decrease the steam pressure in the dryer cans, which in turn increase the
29 moisture content of the paper. As the moisture content increases, the machine's paper
30 measuring system senses the moisture increase in the finished paper and automatically
31 decreases the machine speed to allow for greater drying time. This, of course, has the same

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1 effect as decreasing the machine speed directly by slowing the paper machine drive motors.
2 This is typical of many automatic adjustments to operating speed, which are affected by a
3 forced change in quality, such as increased moisture content.

4 While unacceptable quality and breaks occur at all acceptable machine operating
5 speeds, increased frequency of breaks and diminishment of quality occurs as the operating
6 speed increases. Current automated machine controls do not maximize efficiency by taking
7 into account the loss of unacceptable quality and breaks for determining the appropriate
8 operating speed of a machine. Aside from providing information on quality and breaks,
9 current machine and information system controls do not aid in the adjustment of the machine
10 production to achieve the most efficient or optimal operating speed.

11 Another example, for instance, is the control systems on a wood pulp digester. Pulp
12 mill operators utilize current control equipment that measures, among other characteristics,
13 the kappa number of pulp leaving the digester to determine an acceptable operating speed.
14 As the production reaches or exceeds the digester's designed capacity, the kappa number
15 increases. The pulp mill operators will set a limit on an acceptable higher-than-ideal limit on
16 the Kappa number. This upper limit is established by understanding that additional
17 delignification will occur in the subsequent bleaching process. While the higher limit may
18 be established on a criteria that factors in an estimate of bleaching costs, the pulp mill control
19 system does not actually calculate the cost of additional bleaching. There are no control
20 features presently available that limit the digester operation speed based on the actual current
21 marginal cost of the additional bleaching. Rather, pulp mill operators estimate the bleaching
22 cost based on an average cost.

23 For example, it may be determined that the average additional bleaching activity
24 required to achieve a certain level of additional delignification will cost \$20 per ton of pulp,
25 based on an average cost of bleaching. A pulp mill operator may, therefore, allow the
26 digester to operate at a level that exceeds its capacity because such operation is considered
27 efficient if the additional bleaching costs are actually \$20 per ton. When all variables are
28 considered, however, it may be discovered that the additional bleaching action required on a
29 certain level of marginal operating speed may be measured to actually reach \$100 per ton
30 due to the non-proportional demands for bleaching chemicals, energy, and effluent
31 treatment. Current controls do not calculate from the necessary variables the total additional

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bleaching cost on the marginal operating speed, and subsequently limit digester operations to not incur the additional inefficient bleaching.

Current equipment controls are utilized by manufacturing operators to control certain immediate inventories of items that are directly used by the equipment being controlled. For example, paper machine operating speed may be decreased manually or automatically by machine controls as high-density storage pulp inventory in front of the paper machine is decreased. When the machine controls recognizes an inventory depletion of pulp from high density storage, machine speed or steam pressure to the dryers may be limited to decrease machine operating speed to allow pulp storage to replenish or "catch-up" to desired levels of operation. This control of machine operating speed is, however, based solely on assuring adequate quantity of materials for continued operation, rather than any measure of operating speed based on efficiency.

One problem with current control systems is that they are strictly focused on either one particular piece of equipment's operating characteristics, or at best, focus on monitoring the availability of inflow materials for the piece of equipment. For example, the machine controls for a paper machine monitors the operating characteristics of the machine itself, primarily in the area of quality of the finished product. As discussed above, the controls may also monitor pulp inventory in high-density storage to help assure that inflows are available for continued operation. Current controls do not, however, monitor many, or even most, manufacturing inflows from the time of introduction into the process. For example, the availability of wood through recent purchases and all intervening steps throughout production from wood to pulp held in high density storage for the machine should be factored into the appropriate optimal operating speed of a paper machine. Similarly, a digester operating speed should be determined with a focus on the current efficiency of the bleach plant, based on its operating characteristics, to arrive at an efficient operating speed.

The current control systems also do not factor in many, or even most, events that occur with the product after it leaves the particular piece of equipment. For example, current controls of manufacturing machines do not factor in the many activities that occur after the product leaves the machine. Machine operating speeds are not, for example, tied to the finishing, inventorying and selling processes that occur after the product leaves the manufacturing machine. These activities should, however, have a significant effect on the

1 operating speed of the machine, as the efficiency of the entire manufacturing process is
2 relevant to any one component's operating speed.

3 To maximize operating efficiencies by optimizing the operating speed, control
4 systems should link the entire manufacturing process activities together to analyze all, or as
5 many as useful, potential variables. These activities include the purchase of raw materials
6 and the sales of finished goods. For example, for a papermaking facility the activity of
7 procuring wood in the forest and the selling of finished product should be factored into the
8 operating speed control of the paper machine and all other equipment.

9 An additional problem with current control systems is that any measured efficiency
10 on marginal operating speed is based solely on quantitative and qualitative measurements,
11 rather than total economic efficiency. While the quantitative and qualitative measurements
12 are used to improve the economics of the concern, they do not include one other essential
13 component of total economic efficiency, which is price.

14 In making equipment operating speed decisions, the current control systems fails to
15 account for the price component of the economic efficiency of a particular activity. While
16 productive and qualitative measurements of equipment operations are essential to
17 establishing an appropriate efficient operating speed, the individual price components of
18 input materials, processing or manufacturing, and value of outputs should also be factored
19 into calculating the efficient operating speed of equipment. For example, for papermaking
20 under the current control system, additional steam showers may be added to the
21 papermaking process on a paper machine to increase the operating speed. Current controls
22 systems would dictate operating at the increased rate, without factoring the incremental use
23 of the additional steam.

24 The present invention relates to industries, which have limitations in their current
25 equipment control systems. These industries are suffering from inefficiencies due to
26 inadequate integrated control systems that factor in marginal operating speeds.

27 28 **SUMMARY OF THE PRESENT INVENTION**

29 The present invention relates to a method and system that controls the operating
30 speed of a manufacturing facility. It is an object of the present invention to use a
31 computer program to control the operating speed of a manufacturing facility. It is an

1 object of the present invention to determine a desired operating speed. It is an object of
2 the present invention that the desired operating speed be dependent on at least one
3 economic variable that varies depending on the operating speed. It is a further object of
4 the invention that the operating speed is adjusted (if necessary) in response to the
5 determination.

6 It is an object of the present invention that the system determines a current
7 operating speed of the manufacturing facility, and compares the current operating speed
8 to the desired operating speed. The operating speed is controlled in response to the
9 comparison.

10 In is an object of the present invention that the system determines the desired
11 speed where the economic variable is a cost of manufacturing, and/or manufacturing
12 inflows, and/or manufacturing outflows.

13 The desired operating speed is determined by calculating the cost of
14 manufacturing, the manufacturing inflow, and the manufacturing outflow at a plurality of
15 potential operating speeds. Then the desired operating speed is selected from the
16 potential operating speeds, in an alternative. The desired operating speed is determined
17 by calculating a marginal cost of manufacturing, a marginal manufacturing inflow, and a
18 marginal manufacturing outflow at a plurality of marginal potential operating speeds in
19 another alternative. The desired operating speed is selected from the marginal potential
20 operating speeds and a prior desired operating speed.

21 The economic variable is cost of manufacturing, and the cost of manufacturing
22 includes ascertaining the correlation between operating speed and the cost of
23 manufacturing, in yet another embodiment. The cost of manufacturing may be
24 determined by ascertaining a correlation between operating speed and the per-unit cost of
25 manufacturing inflows and/or the usage of manufacturing inflows. Also, the correlation
26 between manufacturing cost and operating speed may be ascertained by establishing the
27 correlation between manufacturing costs and operating speed of specific equipment or
28 process in a manufacturing facility. In another alternative the correlation between
29 manufacturing cost and the operating speed of a machine includes the manufacturing
30 inflows during breaks and/or while the facility is producing finished product of
31 unacceptable quality. Information needed to obtain this correlation can be obtained in

1 real time, for example, by using the Internet.

2 Another alternative provides that the correlation between manufacturing cost and
3 operating speed is ascertained by establishing the correlation between manufacturing
4 costs and the operating speed of groups of equipment or processes in a manufacturing
5 facility. Also, the purchase price of manufacturing inflows may be assigned, from lowest
6 to highest per-unit cost, to increasing levels of the manufacturing facility's production.

7 Yet another alternative provides that the manufacturing outflow is determined by
8 ascertaining a correlation between operating speed and sales of at least one of finished
9 products and byproducts. The correlation between the operating speed and sales may be
10 ascertained by assigning a plurality of manufacturing outflows to at least one specific
11 portion of the manufacturing facility's production. Alternatively, the correlation between
12 operating speed and sales may include variations in product mix. Product mix is defined
13 as different types of products that can be manufactured on the same machine. For
14 instance, in the paper industry, different grades of paper can be manufactured on the
15 same machine. The manufacturing outflow is determined, from highest to lowest per-
16 unit economic value, for increasing levels of the manufacturing facility's production, in
17 one embodiment.

18 A second aspect of the invention is a method and apparatus that determines the
19 effect of one or more business transactions on the economic efficiency of the production
20 of products in a manufacturing facility. The economic efficiency is dependent on one or
21 more economic variables that vary with operating speed. It includes obtaining the
22 current economic efficiency of the facility and inputting information on the business
23 transactions that affects the economic variables. Information regarding the economic
24 efficiency of the facility may be obtained in real time, for example, using the Internet.
25 Also, the economic efficiency of the facility with the proposed transaction leaving the
26 remaining variables constant is calculated. Then, the result is displayed to the end user.

27 In one embodiment the operating speed of the manufacturing facility is dependent
28 on at least one economic variable that varies depending on the operating speed. In
29 another embodiment, the transactions include one or more of purchase of inflows, sales
30 of outflows, capital additions, capital subtractions, changes to equipment, change in
31 product mix. In a third alternative the business transactions are proposed business

1 transactions.

2 Other principal features and advantages of the invention will become apparent to
3 those skilled in the art upon review of the following drawings, the detailed description
4 and the appended claims.

5 6 **BRIEF DESCRIPTION OF THE DRAWINGS**

7 Figure 1 is a block diagram of the inventive control system's activity of
8 controlling the operating speed of equipment or process in a manufacturing facility.

9 Figure 2 is a block diagram that describes the activity of computing the optimal
10 operating speed of a particular piece of equipment or process selected as the primary
11 focal point. Other equipment or processes in a facility will have operating speed
12 determined from the focus equipment or process.

13 Figure 3 is a block diagram that describes the activity of providing critical
14 ancillary information relating to the marginal operating speed analysis.

15 Before explaining at least one embodiment of the invention in detail it is to be
16 understood that the invention is not limited in its application to the details of construction
17 and the arrangement of the components set forth in the following description or
18 illustrated in the drawings. The invention is capable of other embodiments or of being
19 practiced or carried out in various ways. Also, it is to be understood that the phraseology
20 and terminology employed herein is for the purpose of description and should not be
21 regarded as limiting. Like reference numerals are used to indicate like components.

22 23 **DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS**

24 The present invention is, in one embodiment, a method and apparatus for
25 an integrated control system in a manufacturing facility, or computer program
26 implementing the system, that establishes and implements an optimal operating speed for
27 equipment or processes that enhances the efficiency of the entire activity involved in a
28 manufacturing facility. The present invention can be utilized in a number of
29 manufacturing businesses, particularly process manufacturing, such as steel (and the
30 production of other metals), petroleum and energy. The use of a papermaking facility
31 example in the description is not meant to limit the scope of the invention to the paper

1 industry.

2 The use of the term manufacturing facility in this application shall include any
3 manufacturing plant, any single piece of equipment or process, or groups of equipment or
4 processes that includes a manufacturing activity for the manufacture of a product. The
5 use of the term also could include groups of facilities, particular product lines in a
6 manufacturing company or the entire company itself. The control system, therefore,
7 could encompass more than a single manufacturing plant but rather could be integrated
8 throughout all the plants of an entire company. For example, the operating speed of a
9 machine in facility A of a manufacturing company could be interrelated to the optimal
10 operating speed of a machine in facility B or interrelated to a converting operation.

11 The present invention relates to a method of controlling the operating speed of
12 equipment or processes in a facility by computing and implementing an optimal
13 operating speed for the equipment throughout the entire facility. The computed optimal
14 operating speed is dependent on variables that are correlated with operating speed. The
15 invention includes, in various embodiments, the software used to compute the optimal
16 operating speed, the hardware that implements the control, and the method used in
17 determining the optimal operating speed. In a preferred embodiment the invention also
18 includes a source of real time information, such as the Internet.

19 Operating or production speed is defined as the output, measured in any
20 applicable units. For example, in the paper industry, tones per day for a pulp washer,
21 cords per hour for debarking equipment or feet per second for a paper machine.

22 Operating or production speed is defined as output for particular pieces of equipment
23 (such as a paper machine or a digester), of particular processes (such as a bleaching
24 operation), or of the entire facility. Operating speed may be expressed as a percentage of
25 maximum speed or as the fraction of actual operating time over the total possible time of
26 operation. It may also be reflected as a fraction of output (measured in any applicable
27 units) over the total maximum output. Facility operating speed is the operating speed of
28 a facility, including: one or more plants, one or more product lines of a company, and one
29 or more pieces of equipment or process.

30 The variables that are dependent on the operating speed can include: the variable
31 usage of manufacturing inflows, the variable cost of manufacturing inflows and the

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1 variable economic value of manufacturing outflows.

2 Manufacturing inflows include raw materials and/or other manufacturing supplies
3 that are utilized in the manufacturing process that has either per-unit cost or usage that
4 varies with operating speed. For a pulp and paper manufacturing facility, these may
5 include, but are not limited to, pulpwood, wood chips, secondary or post-consumer
6 recyclable fiber, purchased virgin pulp, purchased secondary or post consumer pulp,
7 water, pulping chemicals, bleaching chemicals, paper additive chemicals, electricity,
8 fossil fuels of any type, purchased steam, paper machine felts, paper machine wires, labor
9 costs (to the extent that it varies with production speed), effluent treatment chemicals and
10 paper finishing chemicals (such as coating and sizing ingredients). Costs for outside
11 services that substitute for activities within the facility should also be included as
12 manufacturing inflows if they vary with Operating Speed. For example, payments to
13 municipalities to handle excess effluent treatment are in lieu of the chemical, energy and
14 other supply purchases that are associated with in-facility effluent treatment, and
15 therefore, should be considered as a manufacturing inflow. The variable usage of
16 manufacturing inflows (or sometimes referred to as manufacturing inflows), is
17 established at different machine operating speeds by computing the effect of operating
18 speed on the usage of manufacturing inflows.

19 To compute the variable usage of manufacturing inflows at various operating
20 speeds for the entire facility, the inventive control system aggregates the variable usage
21 of manufacturing inflows for the separate pieces of equipment or process in the facility.
22 While it is not likely, practical or relevant to include every piece of equipment in a
23 facility for this purpose, each facility operator will be able to use the inventive control
24 system by selecting which equipment to include in the control process. Further, each
25 facility operator can aggregate the results of separate equipment or process usage into
26 grouping of equipment or processes.

27 The information on variable usage of manufacturing inflows could be obtained,
28 either manually or electronically, from other control or information systems in the mill
29 that could provide historical data to create a formula or other computation mechanism to
30 establish the usage at different operating speeds. This information could also be obtained
31 through physical observation by facility personnel or through feedback systems designed

solely to work with this inventive control system.

To effectively measure total efficiency, the inventive control system will convert the variable usage of manufacturing inflows to dollar amounts based on manufacturing inflow costs. These costs are inputs of the inventive control system, to generate a variable cost of manufacturing inflows. The inputs on costs could be performed manually or through other information systems within the facility.

Finished goods and sellable byproducts, which are referred to as manufacturing outflows, can also have a value assigned to help establish the optimal operating speed of equipment based on economic efficiency. These values can vary based on the operating speed of the equipment. This is referred to as the variable economic value of manufacturing outflows. The value assigned could be the net sales price of finished goods. These prices could be input into the inventive control system manually or electronically through other information systems within the facility. They could also be input through physical observation or by feedback systems designed solely to work with this inventive control system.

While the optimal operating speed may be defined in many different ways by a facility operator implementing this invention, in the preferred embodiment it is the operating speed of the entire facility, or part of the facility, that provides the greatest efficiency to the facility. The optimal operating speed of any particular piece of equipment or process may not be its own most efficient or optimal speed, since the optimal operating speed may be measured on the basis of integration of all relevant equipment and processes in a facility. In other words, the equipment may be limited in reaching its own most effective operating speed, if its contribution to the overall efficiency of the facility can be enhanced by operation at a greater or less speed.

The optimal operating or production speed may focus on the operating speed of a particular piece of focal point machinery from which other equipments' operating speed could be established for purposes of effectively controlling and measuring the speed that achieves the greatest overall efficiency of a facility. In the paper industry, a paper machine, for example, would be a logical choice for a focal piece of equipment. This choice allows other equipment or processes to establish their required operating speed based on the requirements of the process flows for the paper machine (these process

flows include manufacturing activities that occur before and after the paper machine). The focal point may first be on the combined operating speed of all the paper machines before segregating the speeds to the separate machines for multi-machine facilities. The term paper machine in the singular discussed herein, therefore, also includes the plural.

The optimal operating speed, in terms of economic efficiency, can be defined as the operating speed that provides the highest amount of positive difference between the facility value of manufacturing outflows and the cost of manufacturing.

Manual or automatic adjustments of the operating speed of a particular piece of equipment or process is made after the inventive control system computes the optimal operating speed. The inventive control system computes a revised optimal operating speed as variables in the process change, such as changes in variable usage or costs of manufacturing inflows, either instantaneously or at a later time. The inventive control system will then be used to either initiate manual or automatic adjustments to the operating speed of the equipment to achieve the new optimal operating speed.

Like other control systems, the inventive control system can also provide ancillary data that will be useful for operations. For example, it can provide information on the effect of deviations from the optimal operating speed. If equipment is not performing at the designated optimal operating speed, the inventive control system could compute and provide information on the deviation's effect on the efficiency (economic or otherwise) of the facility.

The inventive control system will also provide useful ancillary information for activities outside of the controlled environment, such as purchasing and selling decisions in the manufacturing business. For example, in the paper industry, the wood procurement department would be able to access information from the inventive control system to understand the impact that a proposed or accepted wood purchase decision would have on the economic efficiency of the operation.

Another potential source of ancillary information would be the effect that capital improvements, additions or deletions have on the speed and efficiency of an operation. For example, the inventive control system can provide useful information on the effect that a new machine, other piece of equipment, or change in process would have on the optimal operating speed of the equipment in the facility.

1 Generally, the inventive control system may be implemented using a closed-loop
2 control, where feedback indicating the actual speed is used to adjust the speed, or
3 implemented using an open-loop control. An example of a possible embodiment of the
4 control system invention is described in more detail with the use of the accompanying
5 drawings.

6 Figure 1 shows the use of a closed loop-control system version of the inventive
7 control system. Block 101 represents the activity of ascertaining the current operating
8 speed of a particular piece of equipment or process within the facility. Current speed
9 data may also be used in accumulating historical speed data for a particular measured
10 time period, which is then used to set an average speed for a particular time period (as
11 discussed below). Block 103 represents the activity of determining the optimal operating
12 speed of the machines. This activity is diagramed in more detail in Figure 2.

13 Block 105 represents the activity of determining the optimal operating speed of a
14 particular piece of equipment or processes from the output of block 103. This activity
15 involves computing the appropriate operating speed of a particular piece of equipment or
16 process to fulfill the requirements of the machines' running at the optimal operating
17 speed (this may first require a determination of the operating speed of equipment groups
18 or processes at a higher grouping level).

19 It is important to point out that at any given time period, equipment and processes
20 can deviate from the optimal operating speed, and through a process of averaging can
21 still fulfill the needs of the machine. For example in the paper industry, the inventive
22 control system may determine that a pulp washer must operate at a speed of 1,000 feet
23 per minute to achieve optimal operating speed. If the washer operates at 500 feet per
24 minute for 12 hours and then at 1,500 feet per minute for 12 hours, its daily speed has
25 been optimized. The inventive control system can, however, take into account in
26 establishing the optimal operating speed that the washer may experience two different
27 manufacturing inflow usage profiles by operating at different speeds during the day.
28 Historical speed data (accumulated in block 101, as discussed above) may be used in
29 determining current speed, so that a desired average speed is obtained.

30 Block 107 represents the activity of comparing the current speed of the equipment
31 or process determined in block 101 to the optimal speed determined in block 105.

1 Block 109 represents the activity of adjusting the speed of the equipment or
2 process in response to the comparison established in block 107. The arrow from block
3 109 back to block 101 represents the activity of repeating of the above-described
4 procedures in the closed-loop process. The process may be continuously repeated,
5 intermittently repeated, or used once. The order of the steps shown is only the preferred
6 embodiment. Other embodiments include performing the steps in a different order.

7 As mentioned above, Figure 1 illustrates a closed-loop system. An open-loop
8 system would preferably include blocks 103, 105 and 109. No monitoring of current
9 operating speed would occur in the open loop system. Rather, a determination of the
10 machine optimal operating speed (block 103) is followed by the equipment or process
11 optimal speed computations (block 105) which is followed by a change in machine or
12 process speed to the optimal operating speed established in block 105 (block 109).
13 Open-loop control may be particularly useful when machines in the facility have their
14 own speed control.

15 Figure 1 shows that the optimal operating speed is determined in an integrated
16 fashion (i.e. including all relevant facility equipment) established before establishing the
17 optimal operating speed for any individual equipment or processes. This integrated
18 optimal operating speed is established before controlling any one piece of machinery or
19 process because the preferred embodiment of the inventive control system involves an
20 integrated calculation of the efficiency of the entire manufacturing process. Another
21 alternative would be to establish the optimal operating speed of a single piece of
22 equipment or process or groups of certain equipment or processes (for example, the paper
23 machine alone) without establishing the optimal operating speed of all the relevant
24 equipment in the entire facility.

25 In the paper industry, the paper machine(s) is the piece of equipment, which can
26 serve to measure the optimal operating speed, since it is the focal point of production in
27 the papermaking operation. While all machinery can likewise be speed controlled in the
28 same manner, the paper machine operating speed will likely best dictate the operating
29 speed of other equipment. Other equipment could be chosen, however, to establish the
30 operating speed of all the facility's equipment.

31

Figure 2 represents the sub-activity of determining the optimal operating speed of the machine (block 103 of Figure 1). Block 200 represents the activity of inputting all the variable cost of manufacturing inflows. This may be done manually or electronically at the occurrence of the actual purchases. For example in the paper industry, when a purchase of wood is made by the purchasing department of a papermaking facility, either manual data on cost and quantity are entered or such data is automatically transferred from the computer system handling the purchase information.

Inputs may also be made on known price and quantity quotes rather than actually purchase transactions. This may be an effective means of gathering more real-time information. Real-time information may be obtained from the Internet. For example, quoted energy prices may be able to flow directly to the inventive control system to obtain current potential per-unit energy costs.

One purpose of inputting the quantity of each variable manufacturing inflow purchase is to establish the quantities of available resources. This will help determine the optimal operating speed based on the available resources. Further, information on quantity of purchases will aid in determining the variable usage of manufacturing inflow alternatives. For example for the paper industry, the inflow data may establish that pulp wood purchases can only be made to fulfill 75% of the facility's potential operating speed. Additional operating speed will, therefore, have to be met through an alternative variable manufacturing inflow, such as purchased wood chips or market pulp. This may lead to less economic efficiency at higher operating speeds, which results in a lower optimal operating speed compared to a facility that can fulfill its pulp requirements internally.

The inputting of manufacturing inflows may also include the production of ancillary products needed in the manufacturing process. For example, steam generation is needed for many parts of paper manufacturing. Steam may, therefore, be considered a manufacturing inflow in which the per-unit cost of particular quantities of steam could be included as inputs in block 200.

An alternative to treating steam as a manufacturing inflow would be to treat its manufacture as part of the papermaking process of the facility. In this regard, steam generation would have its own variable manufacturing inflow needs. For example, fossil

1 fuel (such as coal or natural gas) would be a manufacturing inflow to the production of
2 steam and would, therefore, be a separate input at the activity in block 200.

3 Block 210 involves a computing or data organizing function of the inventive
4 control system where the information from the variable manufacturing inflow inputs of
5 block 200 is arranged by individual layers of inflows to be retrieved by later
6 computations described below. The results of this activity are the creation of a purchase
7 grid.

8 A manufacturing facility, ideally, purchases its manufacturing inflow items in an
9 increasing per-unit cost fashion based on operating speed. This means that the
10 purchasing departments are securing manufacturing inflows with the lowest per-unit cost
11 before investigating purchases of greater cost. Consequently, if the operations were
12 curtailed, the highest per-unit cost raw materials would not be purchased. Under this
13 arrangement, per-unit cost of inflows is directly correlated to increasing operating speed.

14 More particularly, this would result in the use of a particular item of inflow with the
15 highest per-unit cost to fulfill the last quantity needed by the facility to operate at full
16 speed. Conversely, as speed decreases, less expensive per-unit inflows would be utilized.

17 If this behavior exists or is desired, the purchase grid from the input data in activity
18 block 200 would be layered in the activity block 210 in a fashion of increasing per-unit
19 costs so that inflows are retrieved in a least-expensive-out-first fashion.

20 A simple example of this would be a facility that has two purchases: one purchase
21 layer at \$50 per-unit that covers 75 percent of the potential operating speed and a second
22 purchase layer at \$85 per-unit that covers the remaining 25 percent of potential speed. In
23 establishing the optimal speed (which will become apparent with the full description of
24 figure 2), the inventive control system would utilize the \$50 purchase layer for potential
25 operations up to 75 percent of the potential speed and the more expensive \$85 purchase
26 layer for potential operations that exceed 75 percent of the potential speed.

27 Data arranged in the activity of block 210 would likely be segregated for each
28 category of variable manufacturing inflow. For example, in the paper industry, the input
29 for pulp wood purchases would be arranged in the above manner separately from market
30 pulp purchases.

31 Facility operators will establish their own methodology of what purchase data

1 will be input and how it will enter and exit the purchase grid. Current purchase orders,
2 for example, can be an effective input for the purchase grid. As the orders are input, the
3 activity of block 210 could add them to the purchase grid. The items would later be
4 removed from the purchase grid at an established point in time decided by the operator.
5 In general, the time of deletion from the purchase grid will be based on operator's
6 decision of when the information no longer has relevance for determining optimal
7 operating speeds. This removal could be performed manually or electronically from
8 information systems that track purchases and flows of inventory.

9 Since the optimal operating speed is determined by marginal transactions, the
10 operator may choose only to include those purchases above a certain operating speed.
11 For example, an operator may not want to include low cost purchases that represent the
12 first 50% of operating speed because the operator knows that the facility could never be
13 efficient below this speed.

14 Block 202 represents the activity of establishing the variable usage of
15 manufacturing inflows for individual pieces of equipment or process. The result of this
16 activity is to establish a correlation between the operating speed and the variable usage of
17 manufacturing inflows for a relevant particular piece of facility equipment or process.
18 The data used to establish the correlation would be input manually or electronically from
19 historical data on operations at different operating speeds. It may also likely involve the
20 creation of formulas or other data-solving methodologies, either electronically or
21 manually, to establish the correlations based on the unique characteristics of the facility
22 equipment and processes.

23 The activity represented in block 202 would be performed for each chosen
24 relevant piece of equipment or process of the facility. The potential activities represented
25 in block 202 are numerous. Some examples of equipment for the paper industry are:
26 debarkers, chippers, digesters, grinders, pulp manufacturing refiners, screening
27 equipment, washers, bleaching equipment, stock preparation refiners and chests,
28 cleaners, paper machines, off-machine finishing equipment, roll wrapping and handling,
29 and converting equipment.

30 The usage of manufacturing inflows of a process manufacturing machine could
31 include electricity, steam, water, chemicals, effluent treatment, machine felts, machine

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wires, to name a few. Historical data on prior operations could be gathered to correlate the operating speed of the machine to its usage of inflows. Physical observations can also establish the usage correlations.

Usage could be measured in relation to acceptable output from the particular piece of equipment. For example for the paper industry, if sheet breaks and unacceptable rolls of finished product increase as paper machine operating speed increases, a mathematical relationship to the equipment's increased pulp usage, measured by quantity of pulp required for a given level of acceptable finished product, can be ascertained.

Usage of different types of manufacturing inflows will occur at different speeds of equipment. For example in the paper industry, a paper machine speed increase will likely result in an increase in pulp usage. If the pulp operation of the facility is limited to only supplying 80 percent of the fiber requirements of the paper machine running at full speed, the manufacturing inflow usage of purchased market pulp will be required, whereas operations below 80% may not dictate such usage. Purchased pulp would become a necessary inflow usage at levels above 80%. Alternatively, purchased pulp could be assigned a cost of zero below 80%. The optimal facility efficiency will dictate whether purchased pulp will become part of the manufacturing inflows for speeds below 80%.

Block 212 represents the activity of establishing the variable manufacturing cost for individual equipment or process. This activity involves applying the manufacturing inflow cost from the purchase grid developed in the activity at block 210 to each piece of equipment's variable usage of manufacturing inflows established in block 202. As discussed above, items retrieved from the purchase grid will be done so in a specific order as established by the user of the inventive control system. One possibility, as discussed above, would be based on a lowest-cost-first priority. The results of the activity in block 212 will establish a correlation between potential equipment or process operating speeds and the cost of manufacturing.

Some manufacturing inflow items will be required of more than one piece of equipment or process. For example, electricity will be a manufacturing inflow item that would be needed throughout virtually every piece of evaluated equipment in the facility. It will, therefore, require additional computations or assumptions regarding the usage of

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1 this item at the individual equipment level. For example, an average of actual electricity
2 costs could occur at this level of analysis.

3 Activity block 220 involves the process of solving for the optimal operating speed
4 of individual equipment or process when joined with other equipment or processes to
5 form larger processes or groups of equipment that can have their own measurable
6 operating speeds. The activity in block 220 also involves computing the variable cost of
7 manufacturing of the larger processes or groups of equipment.

8 For example in the paper industry, pulp digesters and bleaching equipment are
9 separate pieces of equipment that can be analyzed in the activity at block 212. This
10 equipment can, however, be grouped into larger categories of production or processes.
11 For example, each separate piece of bleaching equipment can then be grouped together to
12 be analyzed for various operating speeds of the entire bleaching process. Further, since
13 part of the bleaching process involves delignification, it can be grouped with other
14 equipment (such as the digesters) to establish the variable cost of manufacturing in the
15 delignification process. This also shows that equipment can become part of more than
16 one grouping (i.e. bleaching and delignification).

17 Two similar pieces of equipment performing the same function could also be
18 grouped together. For example in the paper industry, two paper machines producing
19 identical printing paper products could be grouped together to determine the combined
20 optimal operating speed of the machines in the printing papermaking process. If other
21 machines in the mill also make another type of paper, such as linerboard, they also can be
22 aggregated with the printing paper machines to establish the optimal operating speed of
23 all paper machines in the manufacturing process.

24 Block 222 of Figure 2 represents the activity of inputting the variable economic
25 value of manufacturing outflows. This activity would involve the inputting of the net
26 per-unit sales price and quantity of finished product and byproduct sold. For example in
27 the paper industry, the finished products could be paper, pulp, or converted paper, and the
28 byproducts sold could be steam, fertilizer filler, spent chemicals, or electricity. Similar
29 to the activity in block 200, inputting could be done manually or electronically through
30 the facility's accounting or other information systems. It could include actual sales,
31 market prices or some other form of sales data.

different machine operating speeds. As discussed above, block 224 provides the per-unit price layers of economic value of manufacturing outflows. As also discussed above, these layers could be arranged by decreasing prices, so that the highest marginal operating speed results in the lowest marginal per-unit sale.

The activity in block 230 of comparing the results in block 220 to the results in block 212 may be done at any desired number of different potential machine operating speeds. Each facility operator could determine the appropriate number of different operating speeds to investigate. As discussed above, for the paper industry the paper machine are the chosen piece of equipment to analyze the facility efficiency at different equipment operating speeds because it can be considered the most significant representation of production equipment in the papermaking process. A facility operator may, however, choose any number of other equipment or processes as the measuring instrument.

The activity in block 240 represents a selection of the optimal operating speed from all the potential operating speed performances calculated in block 230. The activity in block 240 will be dependent on the operator's definition of optimal operating speed.

The desired optimal operating speed may be defined as the operating speed that produces products and byproducts with the greatest excess of variable manufacturing cost over the economic value of manufacturing outflows. This speed also represents the speed at which the largest positive numerical sum can be obtained from the product of subtracting the variable manufacturing cost from the economic value of manufacturing outflows. This numerical sum is referred to as the greatest economic efficiency. If this is the selected definition, then one possibility for the methodology of carrying out the activity of block 240 would be to select from the resulting potential operating speeds in block 230 the operating speed that has a facility performance that achieves the greatest economic efficiency.

As data changes, the inventive control system will establish new optimal operating speeds in the manner described in figure 2 and adjust the equipment speed to achieve the new optimal operating speed as described in figure 1. For example in the paper industry, if a new high per-unit cost wood purchase is input in activity 200, it may ultimately result in a paper machine operating speed of 3,000 feet per minute for a single

1 machine facility. The activity in Block 101 (using a closed-loop control system) may
2 measure that the current machine operating speed is 3,100 feet per minute (based on a
3 prior set optimal operating speed before the expensive wood purchase). The activity
4 represented in block 107 would compare the operating speed determined in block 101
5 with the determined revised optimal operating speed result from the activity represented
6 in block 105 (which for the paper machine, was already computed from activity 103).
7 The activity represented in block 109 would be a 100-foot per minute downward
8 adjustment of paper machine speed from 3,100 feet per minute to 3,000 feet per minute.

9 As discussed above, another important feature of the inventive control system is
10 that it will be able to provide ancillary information for its users. For example, personnel
11 making manufacturing inflow purchase decisions or manufacturing outflow sales
12 decisions could be provided with information regarding the effect of a potential purchase
13 or sale. This information can be provided in real time over the Internet. One possible
14 piece of useful information is whether the proposed purchase or sale price of a
15 transaction is efficient, and therefore, acceptable. The block diagram of Figure 3
16 provides a methodology for providing ancillary information for a proposed purchase
17 transaction. Although the methodology shown is for a purchase transaction, any business
18 transaction or proposed transaction could employ a similar methodology. The Figure,
19 therefore, is not meant to limit the scope of the method or apparatus of only providing
20 ancillary information on purchase decisions.

21 Block 300 represents the activity of inputting information that contains the data to
22 determine the per-unit price and quantity of a potential purchase transaction, such as a
23 wood purchase for a papermaking facility.

24 Block 302 represents the activity of retrieving information from the activity in
25 Figure 2 relating to the current machine optimal operating speed calculations. Some
26 examples of this information are: the current optimal speed, the current facility optimal
27 economic efficiency, the current cost structure of the inventory (from its purchase grid),
28 and the current selection of the highest cost being utilized from the purchase grid at the
29 optimal machine operating speed.

30 Block 304 represents the activity of computing "what if" scenarios with the
31 proposed purchase information input of block 300. The activity involves running

operating scenarios under the methodology described in figure 2 as if the proposed purchase was actually made. This will provide information on the effect that the proposed purchase would have on the operation of the facility.

Block 306 represents the activity of comparing the data obtained from the “what if” scenarios created in the activity of block 304 with the current operations information obtained from block 302.

Block 308 represents the activity of displaying the information obtained from blocks 302, 304 and 306 for the purpose of providing useful information to aid in making the purchase decision. Examples of this information includes comparisons of current operations to “what if” scenarios for the purpose of showing the effect that the purchase has on optimal operating speed and efficiency, the effect that the purchase has on the average cost of raw materials utilized at the current optimal operating speed, information on the effect of the purchase on operating speed and economic efficiency based on different hypothetical raw materials purchase quantities at the proposed price. Information can be obtained in real time, for example by using the Internet. Other embodiments include using look-up tables, or solving equations based on marginal changes in one or more variables.

As mentioned above, a similar methodology could be followed for sales decisions. Further, similar methodology could also be employed to determine the effect on economic efficiency and operating speed for other decisions. These could include decisions on capital equipment additions, capital equipment deletions, proposed changes in the processes, or changes to other operating variables.

It is anticipated that the input activity of blocks 200 (purchasing inflows) and 202 (selling outflows) and the data input and output for the ancillary information could be accomplished at locations away from the manufacturing facility. For example, raw material procurement personnel could enter a proposed purchase of a certain quantity and price of raw material (activity represented at block 300 of Figure 3) into a personal computer, lap-top computer or other remote data input and retrieval device (including wireless) at a remote location. The device could relay the information back to devices at the facility for a computation of the effect that the proposed purchase would have on economic efficiency. This information would be instantaneously relayed back to the

1 device for display (activity in block 308). Similarly, inputs of completed purchases
2 (activity 200) or sales (activity 202) could be immediately input into the inventive control
3 system from remote locations, such as customer locations.

4 While there are many methods of calculating the proper operating speeds based
5 on the many operating variables in the process, the preferred way of carrying out the
6 method of the invention will be through, at least in part, the use of a computer program
7 that utilizes a digital or analog computer processing mechanism. Any or all of the
8 activities associated with establishing an optimal operating speed can, however, be
9 computed or implemented in other means including, but not limited to, manual
10 computations, look up tables, analog control circuits and charts that will perform the
11 calculations necessary to compute the appropriate operating speed of the facility or
12 equipment. One skilled in this art will be able to write computer routines, design control
13 circuitry, or create tables that implement the various steps described herein. The
14 computer program may be run on a "stand alone" computer, to which data is manually
15 inputted, or by a microprocessor that is part of a larger control system, and which
16 receives data automatically from other parts of the control system. Likewise, the output
17 may "stand alone" or be integrated into a larger control system.

18 Monitoring and adjusting the speed of the equipment or processes could,
19 therefore, be performed manually from the data output of the inventive control system. It
20 would, however, be preferred for several, if not most, pieces of equipment or processes in
21 a manufacturing facility to integrate the inventive control system's calculated operating
22 speed directly to the control of the machine's operating speed by means of electronic
23 connection to the equipment. For example, the machine controls could automatically
24 slow the operating speed down to a new optimal operating speed if a change occurs to
25 one or more variables in the entire manufacturing process that dictates a slowing of the
26 operating speed.

27 To establish the electronic connection to the equipment, inputs and outputs from
28 the inventive control system could be integrated with other existing control or
29 information systems in the facility. For example, existing controls of equipment could
30 provide input on the variable usage of manufacturing inflows and also could implement
31 the computed optimal operating speed established by the inventive control system.

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1 Similarly, accounting and other information systems could also provide cost information
2 for the manufacturing inflows, the manufacturing inflow usage, and the economic value
3 of manufacturing outflow information. Ancillary data computed by the inventive control
4 system (discussed above) could also be integrated with the other systems, i.e. the
5 Internet, to provide information to the operators and other departments in the facility.

6 Another possible embodiment of the inventive control system is that it could
7 become a part of the overall machine control systems of equipment or processes and/or
8 become a part of other information systems within the facility. For example, present
9 machine controls, such as control systems on a process manufacturing machine could
10 include the embodiment of the inventive control system.

11 Numerous modifications may be made to the present invention which still fall
12 within the intended scope hereof. Thus, it should be apparent that there has been
13 provided in accordance with the present invention a method and apparatus for the
14 inventive control system that fully satisfies the objectives and advantages set forth above.

15 Although the invention has been described in conjunction with specific embodiments
16 thereof, it is evident that many alternatives, modifications and variations will be apparent
17 to those skilled in the art. Accordingly, it is intended to embrace all such alternatives,
18 modifications and variations that fall within the spirit and broad scope of the appended
19 claims.

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